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Procedia Engineering 11 (2011) 210–215

Engineering
Procedia

The 5th Conference on Performance-based Fire and Fire Protection Engineering

Experimental Study on the Effect of Steel Plant's Natural Smoke

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Abstract

In a full-size large steel plant, we analyzed the temperature distribution, the decline rate of dust and the smoke effect in two cases. The results showed that: natural draft reduced the sinking rate from 0.43 cm/s to 0.35 cm/s, the horizontal spread speed was reduced from 38.87 cm/s down to 30.99 cm/s in the plant; The highest temperature of workshop roof reduced from 76 °C to 60 °C; The layer height rose up from 3 m to 5 m, which made a greater affect on the visibility and it was more helpful for personnel evacuation and fire fighting and rescue activities. From the fire temperature and visibility control perspective, experiment proved that the affect of natural draft is good for the large steel plant.

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Key Words: steel plant; natural draft; experiment; smoke spread

1. Preface

With the rapid development of economic construction, the production and storage space become larger and larger, while the steel structure buildings present vitality in the field of construction of factory as its large space, light weight, plasticity and toughness and construction conveniently[1] advantages etc, which has been adopted by more and more enterprises. However, though the large span steel structure is convenient for enterprise production, it does bring a lot of problems to fire control work. The smoke of workshop is one well worth discussing.

The way of exhaust can be used by mechanical exhaust or natural draft with the opened outside windows[2]. Mechanical exhaust is to discharge the high temperature gas generated in the fire area outside though vent by smoke machines, while natural draft with the help of convection movement caused by indoor and outdoor air temperature difference due to the role and outdoor hot wind effects caused by wind to form the indoor smoke and outdoor air convection[3]. A good smoke exhaust system, could exhaust most of the smoke and 80% of calories[4], which reduced the indoor smoke concentration and temperature greatly, then the smoke mode is selected. Natural draft, due to its advantages of simple structure, low investment and none plus power, is used by more and more large factories. But the existing fireproofing design specification, about the smoke of the design rules, so completely is

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necessary for all kinds of applicable as the smoke building design codes and standard of construction inspection[5,6].

I mainly from the experimental point of view, analysis comparatively of the fire with/without natural draft, get the smoke affect on the environmental of factories, and then study the way of natural draft class of large space steel structure construction is feasible and reasonable. The results on the one hand can provide part of the fire scene simulation parameters, on the other hand it also can provide some basic data for predict the spread of such fire, smoke, fire fighting and engineering design.

2. Natural draft experiment

2.1. Experimental Design

This paper selected a steel plant to be demolished as experimental subjects, which is 60 m in east-west and 30 m in north-south, and is a single main building with a sloping roof, the highest of which is 9 m and the roof lowest point 8 m, on the top roof there are two windows(the windows size of $6\text{ m} \times 3\text{ m}$), a row of steel columns (1-11) are fixed up arranged from west to east in the middle, at 5 m height there is a beam with a east-west, the distance between columns from north to south is 15 m. Side Pull Plastic Windows are used as the plant outside windows, color steel sandwich is used for the roof and retaining wall, then all doors and windows and building envelope components intact, almost no damage leakage, the profile of the plant is shown in figure 1.

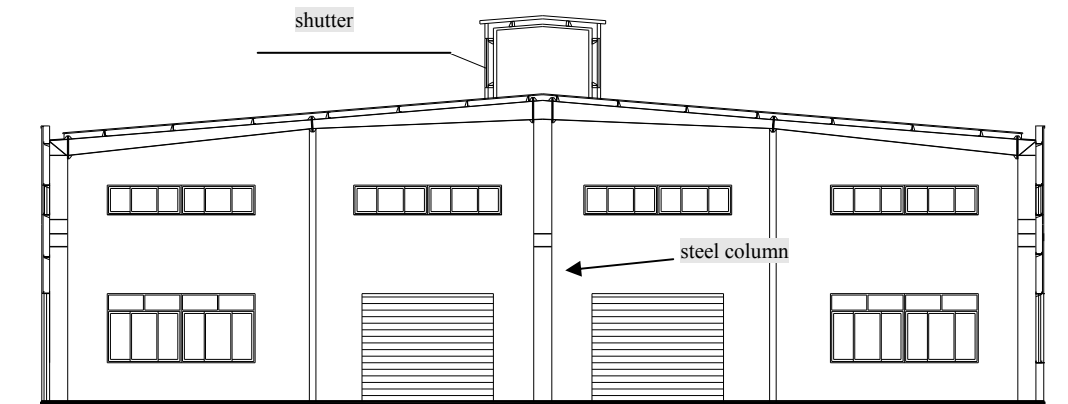


Fig.1. the profile of the plant in north-south

For comparative analysis, this experiment was divided into two experiments with and without natural smoke. This paper analyses the vertical and horizontal smoke spread rate, smoke layer height, the sinking speed and so on, on this basis, focusing on comparative analysis the differences of gas properties between with natural smoke and smoke-free natural, the overall experimental results and the fire development.

Group I : origin of fire is arranged in the middle of two shutters of the plant, and the fire source is made up eight oil basins filled with 3 Kg diesel fuel, the windows are closed and the smoke spreads within the plant;

Group II : origin of fire is arranged in the middle of two shutters of the plant, and the fire source is made up eight oil basins filled with 3 Kg diesel fuel, the windows are open, natural draft is applied.

Experimental device

2.1.1. fire and the fire development model

This experiment used oil basin of fire with the same size 8 oil basins in which is filled with diesel fuel as the fire source, which is shown in Figure 2. When experiment, these eight oil basins were put on the $2.4\text{ m} \times 1.2\text{ m}$ of oil frames, which is lifted up by four fine wire and the upper is connected with two thick wire, hanging on the roof steel frame and connecting with the mass sensor in order to obtain fire fuel mass loss rate. Before the experiment, each oil basin was filled with 3 Kg diesel fuel using the pounds that weigh fuel.

Experiments and studies had shown that the fire heat release rate is changing over time^[7] From fire to the strong phase, heat release rate generally increased exponentially by the time which could be expressed as the fire increased by t^2 or called t^2 fire^[8~9], $\dot{Q} = \alpha t^2$, \dot{Q} for the fire heat release rate, kW; α for the fire growth coefficient, kW/s²; t for the development time of the fire, s.



Fig.2.schematic layout of experimental oil basins

2.1.2. Fuel quality loss collector

During the experiment, the United States CELTRON STC S-type bi-directional tension is used to real-time records the quality of fuel consumption, and it's connected with the United States Agilent Agilent 34970A data acquisition system through Data line use to process and analysis the date.

2.1.3. Temperature Acquisition System

A diameter of 1.48 mm K-type nickel chromium-nickel silicon thermocouple is used as a temperature acquisition device. There were 26 K-type in the experiment, in which 18 were decorated above the fire source, then since the fire started just above the vertical distribution of 0.4 m with the number for the Sh1 ~ Sh18, Sh1 ~ Sh4 0.2 m spacing to each other were used to measure the temperature of the fire source, Sh5~Sh18 0.5 m spacing to each other were used to measure the temperature of the smoke above the fire; Horizontal distance to 2 m high, from the fire source of the center of a arrangement of 2 m intervals, thermocouples were planned to measure the temperature change at 2 m height during the experiment.

2.1.4. Image Acquisition System

Image acquisition system is mainly being low by Samsung Ultra Color Camera SCC-B2007P, fine 1/3 inch EX-view HAD CCD (47 million pixels a few) chip and digital signal processing (DSP)[10]. CCD Continued camera shooting the process of combustion, then digital image was get though screen capture card, after computer processing, we could make sure the changes of the fire and smoke with time and knew the flue gas velocity parameters.

During the experiment, radiation heat flow meter, graduated scale, guns, stopwatch, plywood and other equipment were used, each system connections diagram[10] is shown in Figure 3.

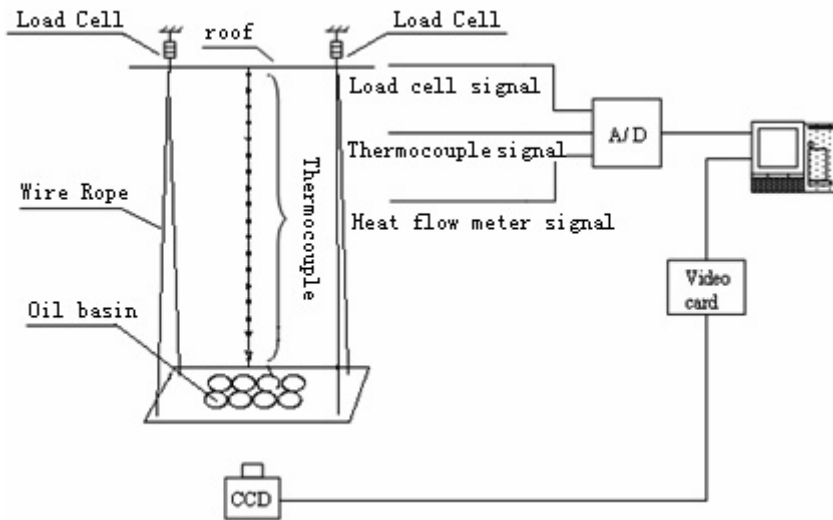


Fig.3.connection diagram of experimental device

3. Experimental process and results

3.1. Experimental process

On the experiment day, it's clear weather and the temperature outside is 11.0°C with 0.15 m/s southeast wind, and there were two experiments. First of all, natural Smoke-free experiment was made, before the experiment, the shutters were plugged with plywood trying to make it tight, seamless joints make it tight, seamless joints. During the course of the experiment, special people was asked to observe and record the experimental process.

After the experiments were all reached their respective positions, and completed the preparation, the experiment begun. First the fire people lights sticks, for ignition. Once the oil pan was ignited, the time people begins to record time, video recorder begins to camera, and the operator starts the program. As the experiment, when the smoke height reached 2.5 to the floor, all the experiments evacuated to the outside plant, and kept recoding the fire until the fire extinguish.

After completely smoke emissions, the experiments stored and recorded results, checked and replaced the experimental equipment, and removed the plywood to prepare for the next experiment. We checked carefully to make sure all the instruments normally, then begun the next one, repeated the above process, observed and recorded the smoke spread properties this time. After the experiment(Gas completely drained, fire reduced the heat), we ordered the equipment, gathered experimental data. The process of the two experiments are shown in figure 4~5, the phenomenon statistics is shown in table 1.

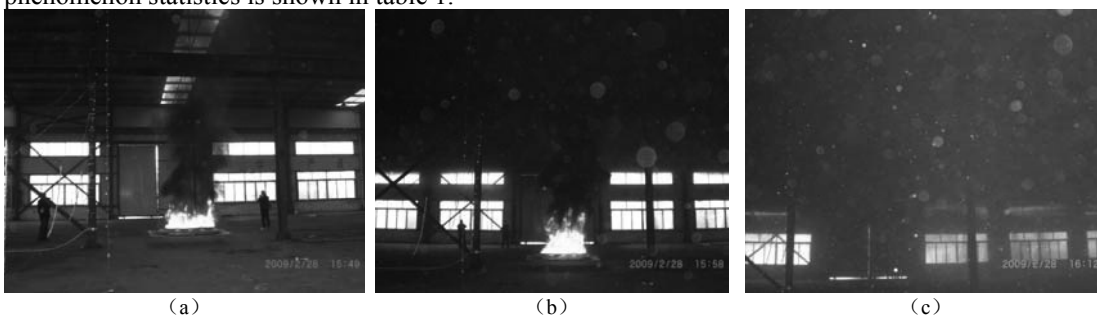


Fig.4.smoke spread process map with no natural smoke



Fig.5.smoke spread process map with natural smoke

Table.1.results tables of two experimental

| Time to ignition /s | no natural smoke | natural smoke |
|---------------------|---|--|
| 60 | light rock | —— |
| 129 | smoke layer height of 6.5 m from the ground | —— |
| 194 | —— | Sh1 bad(Exceed 1 200 ℃) |
| 280 | Sh1 bad | —— |
| 379 | flame roots color is blue-green | —— |
| 441 | smoke layer height of 5 m from the ground | —— |
| 505 | —— | sound and small fire |
| 679 | wood white (thermal decomposition) | smoke layer height of 5 m |
| 740 | —— | board is lit, Oil boiling |
| 811 | Fire height 3m,smoke3.5 m from the ground | —— |
| 872 | Smoke layer back, height from the ground rise | north window is opened |
| 927 | Left smoke layer 3 m,7th Oil basin of small fires | —— |
| 1010 | —— | 1~4th Oil basin crush out |
| 1060 | two share the flame increasing the oil boiling sound, wood continues to run the white smoke | 7th Oil basin crush out |
| 1170 | 1,2,3,6th crush out, 4,5,8th burning | —— |
| 1247 | 8th Oil basin crush out, 4,5th burning | 5th Oil basin crush out |
| 1299 | All of Oil basins crush out but 5th | —— |
| 1387 | fire crush out | 8th Oil basin crush out, the board burning |
| 1440 | open the door | the board keep burning |
| 1688 | —— | the board crush out, experiment over |

Note: The table Sh1 said thermocouple number, dash indicates no record of the moment

3.2. Experimental results and analysis

By comparing experiments, we get the smoke layer height of two group, the smoke temperature and the speed of Subsidence and horizontal, which are shown in table2~3.

Table.2.smoke layer height and temperature comparison tables of two experiments

| | roof highest T(℃) | highest at 2m from the ground(℃) | Smoke lowest H (m) |
|------------------|-------------------|----------------------------------|--------------------|
| no natural smoke | 70 | 32 | 3 |
| natural smoke | 60 | 27 | 5 |

Table 3 smoke speed comparison tables of two experiments

| | sinking speed (cm/s) | | | | Horizontal spread speed (cm/s) | | | |
|------------------|----------------------|-------|------|-------|--------------------------------|-------|------|-------|
| | east | south | west | north | east | south | west | north |
| no natural smoke | 0.40 | 0.37 | 0.40 | 0.55 | 57.8 | 37.5 | 40 | 20.17 |
| natural smoke | 0.33 | 0.28 | 0.33 | 0.46 | 43.3 | 28 | 33 | 19.67 |

Through experiments we found: With natural smoke, the smoke layer 680 s down to 5 m, no further decline after, the lower visibility better, when no natural smoke, the smoke layer 441 s down to 5 m, 927 s down to 3 m, the lower part of poor visibility; With natural draft, the roof smoke layer maximum temperature is 60 °C continued the 100 ~ 300 s, when no natural draft, the maximum temperature is 70 °C continued the 100 ~ 800 s; With natural draft, the highest temperature of 2 m away from the ground is 27 °C inside, and when no natural draft, the temperature rises up to 32 °C; smoke layer sinking speed is more great smaller than the horizontal spread speed, which will be littler when natural draft.

4. The results

- 1) There is little effect on the fire combustion conditions in the steel plant no matter natural draft or not.
- 2) When natural draft, the smoke temperature at the roof is lower and the continued time is shorter than non-natural draft, especially when non-natural draft the high fire makes the plant collapse easier than natural draft.
- 3) Because of the outside windows, the high temperature gas could be discharged in time, the thermal radiation as well as the condition temperature are both reduced.
- 4) When no natural draft, the average sinking speed of flue gas is 0.43 cm/s while the average horizontal spread speed is 38.87 cm/s, the layer height is 3 m away from the ground at 927 s, the condition becomes more and more disgusting; but when natural draft, most smoke discharges outside through the outside windows, the average sinking speed of flue gas is 0.35 cm/s, and the average horizontal spread speed is 30.99 cm/s, the lowest height of layer is 5 m in the whole experiment, and there is more significant effect for natural draft.
- 5) For large steel plant, the outside windows can play a better effect in the condition of no wind or breeze. However it must be noted that natural draft could be effect of the external environment easily, so outdoor temperature, wind environment and so on should be given full consideration while we design the smoke.

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